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What a Decade (2006–15) Of Journal Abstracts Can Tell Us about Trends in Ocean and Coastal Sustainability Challenges and Solutions

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Text mining and analytics may offer possibilities to assess scientists' professional writing and identify patterns of co-occurrence between words and phrases associated with different environmental challenges and their potential solutions. This approach has the potential to help to track emerging issues, semi-automate horizon scanning processes, and identify how different institutions or policy instruments are associated with different types of ocean and coastal sustainability challenges. Here I examine ecologically-oriented ocean and coastal science journal article abstracts published between 2006 and 2015. Informed by the Institutional Analysis and Development (IAD) framework, I constructed a dictionary containing phrases associated with 40 ocean challenges and 15 solution-oriented instrument or investments. From 50,817 potentially relevant abstracts, different patterns of co-occurring text associated with challenges and potential solutions were discernable. Topics receiving significantly increased attention in the literature in 2014–15 relative to the 2006–13 period included: marine plastics and debris; environmental conservation; social impacts; ocean acidification; general terrestrial influences; co-management strategies; ocean warming; licensing and access rights; oil spills; and economic impacts. Articles relating to global environmental change were consistently among the most cited; marine plastics and ecosystem trophic structure were also focal topics among the highly cited articles. This exploratory research suggests that scientists' written outputs provide fertile ground for identifying and tracking important and emerging ocean sustainability issues and their possible solutions, as well as the organizations and scientists who work on them.

Keywords: emerging issues, horizon scanning, policy solutions, institutional analysis, text mining, discourse analysis

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INTRODUCTION

Oceans, coasts, and estuaries provide society with wide-ranging, valuable resources and services that are central for societal well-being, yet they are affected by sustainability challenges arising from human exploitation, global environmental change, and upland pollution and development (e.g., Worm et al., 2006; Dupont and Pörtner, 2013; Barange et al., 2014; Johnston et al., 2015; Gleckler et al., 2016). These are amplified by the mobile nature of many wildlife resources (Schlager et al., 1994; Queiroz et al., 2016), difficulties in effectively monitoring and enforcing regulations

(Bisack and Das, 2015; Rudd, 2015a), governance challenges that arise due to the occurrence of marine resources in regions across or beyond government jurisdictions (Berkes et al., 2006; Cullis-Suzuki and Pauly, 2010), and conflicting mandates and other institutional-related uncertainties within governments and management agencies (Young, 1998; Rudd et al., 2003; Jentoft and Mikalsen, 2004).

Science is not yet settled for many important ocean and coastal management challenges (Rudd and Lawton, 2013; Rudd, 2014) and scientists themselves have very different perspectives on how science should be used at the science-policy interface (SPI), their roles as scientists in SPI boundary spanning efforts, (Rudd, 2015b) and on the role of particular policy instruments in helping to solve the challenges upon which they focus. For some emerging challenges, there may be a scarcity of scientific knowledge and paucity of work on potential policy interventions or investments to counter potential threats. For other challenges, such as fisheries management and conservation for example, there has been abundant scientific research spanning decades but the policy interventions needed to remedy the adverse effects of fishing are context-dependent and contested. This is perhaps most vividly illustrated in the ongoing international debate over the effectiveness of marine protected areas (MPAs) as an instrument for fisheries management and environmental conservation (Pauly et al., 2002; Caveen et al., 2013; Hilborn, 2015; Lubchenco and Grorud-Colvert, 2015).

Haas (1992) theorized that epistemic communities, which are networks of knowledge-based experts, may be allied on four key characteristics: shared normative beliefs regarding the rational for social action; shared causal beliefs commonly held within their research domain and which link policy action and outcomes; shared notions of what comprises credible knowledge; and shared views on policy practices or interventions that enhance societal well-being. Since Haas's original research on epistemic communities, there has been further environment-oriented research on discourse coalitions (e.g., Caveen et al., 2013; Nursey-Bray et al., 2014; Ritchie, 2014), advocacy coalitions (e.g., Weible and Sabatier, 2005; Caveen et al., 2013), and, most recently, instrument constituencies (e.g., Voß and Simons, 2014; Béland and Howlett, 2016). A common theme among recent work is that there may be substantial diversity among scientists regarding their views on preferred policies or interventions and the processes by which those influence society, even among those that share notions of what comprises credible knowledge. A wide variety of intervention or investment options are possible to address societal challenges (Ostrom, 1999, 2005, 2009; Sunstein, 2014), including: new theorization and modeling; technological development; rule development and enforcement; monitoring and data collection; institutional innovations; restoration of depleted capital stocks; and efforts to reshape the values of individuals or firms so that their behavior better aligns with societal goals. Even among scientists within an epistemic community we should expect that diverse views, potentially based on a mix of personal values and professional motivations, may exist regarding their willingness to engage in boundary-crossing activities (Rudd, 2015b) and in preferred policy instruments.

How scientists frame ocean sustainability challenges and the emphasis that they place on particular policy instruments or other investments to help solve ocean challenges should be reflected in the language they use in their scientific writing and in the literature upon which they draw to support their arguments. Science writing is dense, concise, and reflects both technical issues and the values and concepts important within a field (Hyland, 2004). For research focusing on the implicit instrument preferences of social and natural scientists in ocean science and management research, article abstracts can provide a rich data source on which to apply text analytics and mining, with the objective of identifying language-sharing characteristics that could be used to help identify research trends and the epistemic communities who work on various issues.

The purpose of this research is to conduct a preliminary exploration of the potential of using journal abstracts to identify emerging ocean and coastal sustainability challenges, and the prevalence of different types of potential solutions associated with those challenges. Specifically, my research questions in this text-oriented exploratory research included: Are there differences in the frequency with which keywords or phrases relating to instruments or strategies (i.e., potential solutions) co-occur with those relating to different types of ocean challenges?; Does the frequency at which text associated with particular ocean challenges and possible solutions vary temporally across all articles?; and Does the frequency at which particular text associated with particular ocean challenges and possible solutions vary between relatively highly- and lower-cited articles? The latter two questions are motivated by the idea that cutting edge ideas and methods that define and drive epistemic communities might be productive areas for further detailed assessment such as expert interviews or bibliometric research.

METHODS

Theoretical Framework

The Institutional Analysis and Development (IAD) framework (Ostrom, 1990, 2005; Ostrom and Ostrom, 2004) can be used to identify and classify rules, norms, and strategies (Crawford and Ostrom, 1995) that help shape human behaviors by altering the incentives that they face. When cast in an ocean-oriented, asset-based context (Rudd, 2004, 2010), both rules (i.e., boundary rules governing actors' entry and exit to the action arena; authority rules regarding how, where, and when activities are conducted; information rules about monitoring and reporting; scope rules regarding permitted, prohibited, or required outputs and outcomes; and payoff rules that alter incentives) and investments (e.g., education, training, building social networks, technological advance, ecological restoration, etc...) can be viewed as potential targets for policy action (**Figure 1**). Further, initiatives can be undertaken to shift social norms and peoples' beliefs (so that behavioral change follows-see Sunstein, 2014), so as to help insulate vulnerable portions of society from the effects of exogenous driving forces through capacity-building investments (Adger et al., 2005; Smit and Wandel, 2006), or develop new models for governance and management (e.g.,

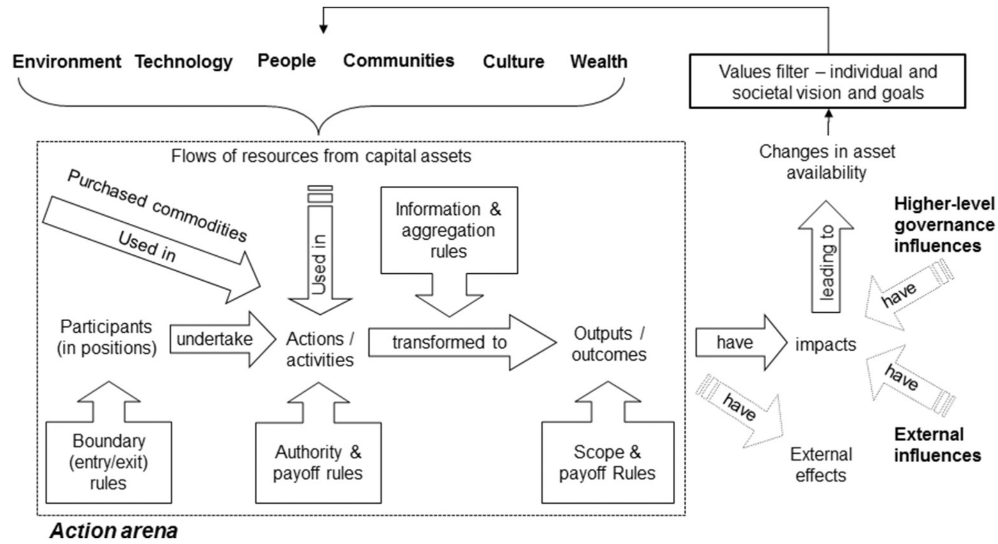

FIGURE 1 | Basic capital asset-based IAD framework (adapted from Sutton and Rudd, 2016).

Slocombe, 1993; Sorensen, 1997; Armitage, 2005; Folke et al., 2005; Leslie and McLeod, 2007).

At the operational level (**Figure 1**), the action arena can thus be conceived as a cyclical structure that is affected by, and affects, other systems across various geographical and temporal scales. While not shown here, action arenas also exist at higher levels (Ostrom, 1990, 2005; Rudd, 2004, 2010) where the outcomes of political processes include broad policy directives, legislation, and coarse-scale resource allocation, and where implementation processes affect finer-scale choices about where, when and how to invest in capital assets, in the acquisition of new knowledge, or in actions aimed at increasing compliance with existing rules.

Article Search Strategy

The goal of the article search was to construct a database of ocean science-oriented academic articles from which to extract abstracts that could be used to develop a dictionary of categories describing ecologically-oriented ocean sustainability challenges and instrument-specific solutions. Given my focus on recently emergent ideas and methods that might be areas for future detailed assessment, and due to the rapidly escalating number of articles published over the past decade, I constrained the search to the most recent decade for which full Web of Science records were available. Following general strategies for content analysis (Krippendorff, 2013), I first conducted a broad 10-year search of the ocean science literature using Thomson Reuter's Web of Science core collection (Science Citation Index Expanded and Social Sciences Citation Index; 2006–2015; journal articles and reviews only; English language only). The search combined the terms (TOPIC = ocean * OR marine OR estuar * OR coastal) and resulted in a total of 203,348 article hits.

Full records for those articles were downloaded and used as the baseline for the second phase of the search. The full download contained articles outside the scope of this study (e.g., marine geology, atmospheric science, land management in "coastal" plains, etc...). An iterative process was used to further refine and structure the dataset, constraining it to include only articles that fell within the scope of this study's focus on marine ecosystems and living resources. Because marine species are influenced by physio-chemical conditions, the ocean system boundary demarcation is fuzzy. To limit the scope of this study, I retained articles that focused on topics such as benthopelagic coupling, ocean-atmosphere flux but not topics such as cloud albedo, which were more marginal to living resources. Due to the importance of upland processes on coastal ecological systems, I retained articles on the influence of upland pollution and nutrient loading on coastal waters.

The text analysis was conducted with the QDA Miner/Wordstat software package (provalisresearch.com). I first used topic modeling to filter research topics clearly outside the scope of this research and then iteratively used a variety of tools (e.g., phrase extraction, "query by example," thesaurus searches) to further winnow the selection to articles that dealt with ecologically-oriented ocean sustainability challenges and their potential solutions. At the start, the abstracts contained >8.1 million words; a stop list (i.e., list of excluded terms and phrases) was constructed for common words and phrases (i.e., those words and phrases without cognitive content or that were ambiguous in meaning), eliminating 4.05 million words from the analysis.

Coding Strategy

Coding was conducted by paragraph and coding themes were first categorized for well-established environmental challenges (e.g., ocean warming, overfishing, etc...) and theoretically-guided terms regarding policy instruments (based on the IAD framework, outlined above). Additional categories were then added iteratively as the categorization continued. For instance, if after five rounds of query-by-example on longline fishing bycatch (i.e., one starts with a single abstract on the topic of bycatch and then expands the search iteratively, identifying other abstracts that closely align with the content from the original example, until saturation is reached) I found 300 relevant abstracts, all would then be initially coded as "bycatch" challenges. Within that group, there may also have been research on habitat destruction by fishing gear, so new categories that were identified during the search process were included as topics for subsequent searches. I drew substantially on phrases to construct the dictionary; individual words were often more ambiguous than phrases and resulted in too many false positive coding instances (e.g., "acidification" relates not only to ocean acidification but is also used in marine-oriented molecular biochemistry).

In all, I developed a nested hierarchy of categories that covered ocean sustainability challenges relating to environmental change (18 categories: *algal blooms and toxins*; *climate change—general*; *climate change - ocean warming*; *contaminants*; *fisheries bycatch*, *discarding, entanglement effects*; *habitat degradation* due to fishing; *ecosystem trophic structure change* due to fishing; *heavy metals*; *human health and disease*; *invasive species*; *marine and plastic debris*; *ocean acidification*; *oil spills*; *overfishing*; *sea-level rise*; *seafood trade and market demand*; *spatial issues—general*; *terrestrial influences - general*), general social concerns relating to environmental management (4 categories: *environmental conservation*; *economic impacts*; *justice and fairness*; *social impacts*), general issues regarding fisheries and aquaculture management (6 categories: *fisheries management - general issues*; *aquaculture*; *compliance issues*; *non-fishing marine tourism*; *ornamental fisheries*; *recreational fisheries*), issues relating to the conduct of fisheries (3 categories: *fishing mortality*; *fishing strategies*; *target species*), general fishery sectors (2 categories: *artisanal and subsistence sector—general*; *industrial sector—general*), and specific types of fisheries (7 categories: *gillnet*; *handline and trolling*; *longline*; *other types of fisheries*; *seine*; *trap*; *trawl*). Specific words and phrases were thus aggregated for each category, which was then treated as a single entity in further analyses. For example, the category *Algal blooms and toxins* represented 16 different word and phrases: algal blooms; blooms; dinoflagellates; HAB; HABs; harmful algae; harmful algal blooms; hypoxia; nutrient concentrations; nutrient enrichment; nutrient loading; paralytic shellfish poisoning; PSP; PSP toxins; toxin; and toxins (redundant words or phrases not removed).

For the operational-level solutions, I focused on one strategy relating to *initiatives to change social norms and individual values* and nine types of policy instruments: (1) *boundary rules—licensing and access rights* relating to resource access through mechanisms such as licensing and the assignment of property rights; (2) *authority rules—gear and vessel restrictions* relating to how activities can be undertaken (e.g., fishing vessel size and technology restrictions); (3) *authority rules—temporal restrictions* relating to temporal restrictions (e.g., fishing seasons); (4) *authority rules—spatial restrictions* relating to MPAs, fishing area closures, and marine spatial planning; (5) *information rules—monitoring and reporting* requirements; (6) *information rules—labeling and information* relating to stewardship and certification programs (e.g., eco-labeling of dolphin friendly capture methods); (7) *scope rules—restrictions on landing size, types, or daily bag limits* relating to types of outputs; (8) *scope rules—restrictions on landing amounts and quotas* relating to aggregate outputs; and (9) *payoff rules—financial incentives* relating to undertaking specified activities or achieving desired outcomes (e.g., Payment for Ecosystem Services schemes, taxes, sanctions). I did not include aggregation rules, which typically relate to decision-making processes (e.g., committee voting rules) and are of more importance at higher political levels of analysis.

For the implementation level, six categories were developed, three relating to general management strategies (*co-management strategies*; *ecosystem-based fisheries management* [EBFM] *strategies*; *Integrated Coastal Zone Management* [ICZM]) and three other topics (*investments in people, technology or infrastructure*; *fisheries science and assessment*; and *enforcement decisions and initiatives*).

Note that a full list of the challenge and solution categories is presented later in **Table 2**. See Supporting Information S1 for a full list of words and phrases included in each theme.

Analysis

Given this was an exploratory analysis, my first research question was addressed in a descriptive manner by examining correspondence between coding frequencies for ocean sustainability challenges and possible solutions. The purpose of this analysis was to ascertain in general terms if it is feasible to identify if and when particular policy instruments were applied to particular ocean challenges.

The second and third research questions compared category frequencies across years or citation quintiles. The expected frequency for each term, based on its occurrence in article abstracts published between 2006 and 2013 inclusive, was compared to observed frequencies in 2014–15 to identify those categories that were occurring more or less frequently (z value) than expected. Multidimensional scaling (MDS) was also used to reduce dimensionality and position issues in 3-dimensional space and to relate category occurrence to year of publication. All tests were carried out using WordStat.

RESULTS

After coding, 50,817 cases (25.0% of the full ocean science download for 2006–2015) contained at least one coded paragraph (84,336 paragraphs were coded in total—in some journals, abstracts could contain paragraph breaks) and were retained for the final analysis.

Challenges and Solutions

Table 1 summarizes the correspondence between, on the one hand, abstracts coded as focusing on one or more ocean sustainability challenges and, on the other hand, one or more possible policy instruments or management strategies/investments. For each challenge, the intersecting cell for each possible instrument or strategy shows the proportion of times that particular solution co-occurred with the challenge (i.e., each row sums to 100%). For example, phrases associated with the topic *sea level rise* occurred

TABLE 1 | Correspondence between ocean challenge and possible solution categories*.

	Overall occurrence frequency			High-level strategy/investments: percent (%) of mentions				Operational-level strategy/investments: percent (%) of mentions											
	Number of time that a challenge term was mentioned	**Number of times that a solution term was mentioned**	**% times in which any solution term was mentioned**	**Co-management strategies**	**Ecosystem-based fisheries management strategies**	**Integrated coastal zone management strategies**	**Investments in people, technology, or infrastructure**	**Fisheries science and assessment**	**Enforcement decisions and initiatives**	**Boundary rules -licensing and access rights**	**Authority rules -gear and vessel restrictions**	**Authority rules -spatial restrictions**	**Authority rules -temporal restrictions**	**Information rules -monitoring and reporting**	**Information rules -labeling and certification**	**Scope rules -restrictions on landing size, types, or daily bag limits**	**Scope rules -restrictions on landing amounts and quotas**	**Payoff rules -financial incentives**	**Initiatives to change social norms and individual values**
ENVIRONMENTAL CHALLENGES																			
Algal blooms and toxins	7,123	416	5.8	4.6	4.6	5.3	**10.3**	3.8	5.8	2.6	2.2	18.8	0.5	**27.6**	0.0	0.0	**12.3**	0.7	1.0
CLIMATE CHANGE																			
General	16,619	1,566	9.4	**25.0**	5.6	10.5	8.9	5.3	3.1	3.8	0.5	22.5	0.1	7.7	0.0	0.3	1.9	1.8	3.1
Ocean acidification	1,499	91	6.1	**22.0**	7.7	1.1	8.8	7.7	2.2	2.2	0.0	27.5	0.0	7.7	0.0	0.0	**8.8**	2.2	2.2
Ocean warming	1,379	146	10.6	9.6	3.4	3.4	4.8	3.4	5.5	1.4	0.0	**51.4**	0.7	8.9	0.0	1.4	2.7	2.1	1.4
Sea-level rise	3,034	350	11.5	**29.1**	2.9	**27.1**	**10.9**	0.6	2.9	4.6	0.0	14.3	0.3	3.7	0.0	0.0	0.3	2.3	1.1
Contaminants	14,357	514	3.6	6.0	2.1	3.1	7.8	3.3	**10.1**	3.5	1.2	18.5	0.4	**35.4**	0.0	1.8	2.5	0.8	3.5
ENVIRONMENTAL EFFECTS OF FISHING																			
Bycatch, discarding, entanglement	1,611	847	52.6	2.5	6.3	1.4	7.0	10.2	4.4	2.0	**17.7**	18.4	**2.4**	15.7	0.1	3.0	5.2	2.5	1.4
Habitat degradation	9,139	1,617	17.7	8.5	**8.3**	7.2	8.7	5.8	5.2	3.8	1.2	31.8	0.7	9.4	0.2	1.1	2.4	2.5	3.2
Ecosystem trophic structure	6,692	1,048	15.7	6.4	**18.8**	2.0	4.3	9.7	2.0	1.3	4.0	33.2	0.6	10.9	0.0	1.4	2.5	1.4	1.4
Heavy metals	11,670	310	2.7	5.2	1.6	3.2	7.4	1.3	6.5	3.9	1.0	17.4	0.0	**39.4**	0.0	**4.2**	5.5	0.3	3.2
Human health and disease (zoonotics)	3,481	221	6.3	10.0	0.5	3.2	5.9	3.2	**38.5**	2.3	0.5	17.2	0.0	16.3	0.0	0.0	0.9	0.5	1.4
Invasive species	3,345	357	10.7	8.4	7.0	2.0	**12.6**	3.6	**10.4**	1.4	1.4	**35.9**	0.3	13.4	0.0	0.8	0.3	1.4	1.1
Marine and plastic debris	1,284	139	10.8	5.8	4.3	5.8	**10.1**	3.6	9.4	4.3	4.3	16.5	0.7	**19.4**	0.0	0.7	0.0	2.2	**12.9**
Oil spills	1,257	138	11.0	10.1	2.2	10.1	**10.1**	5.1	**15.2**	5.8	0.7	21.7	1.4	12.3	0.0	0.0	0.0	2.9	2.2
Overfishing	1,839	1,103	60.0	5.4	7.1	1.5	4.1	**14.8**	4.3	3.5	3.1	31.6	2.3	10.4	0.1	3.0	5.0	2.4	1.5
Seafood trade and market demand	2,010	699	34.8	15.3	2.9	6.3	4.6	6.4	7.0	**8.7**	1.7	17.0	1.6	6.9	**1.1**	2.3	4.7	**10.0**	3.4
Spatial issues-general	21,155	2,579	12.2	5.9	6.0	3.5	5.1	7.7	4.0	2.1	2.4	**46.2**	0.6	10.7	0.1	1.4	2.4	1.0	1.0
Terrestrial influences-general	6,913	1,371	19.8	10.9	**9.3**	**11.5**	8.2	2.8	4.2	2.4	1.1	34.0	0.1	10.4	0.0	0.3	0.7	1.6	2.6
SOCIAL CONCERNS-GENERAL																			
Environmental conservation planning	8,961	3,313	37.0	10.9	**7.9**	5.0	5.9	4.1	5.8	2.9	2.2	**39.5**	0.7	7.8	0.1	1.0	1.5	2.7	2.2
Economic impacts	3,526	1,561	44.3	11.3	4.5	7.4	6.1	7.5	5.2	6.8	2.4	24.4	0.8	7.0	0.3	1.3	4.5	**7.8**	2.6
Justice and fairness	1,378	673	48.8	**21.7**	5.3	**12.5**	4.6	3.7	5.3	**7.7**	1.0	20.1	0.6	4.3	0.1	0.3	3.6	4.0	**5.1**
Social impacts	5,561	1,925	34.6	**21.5**	4.7	7.2	4.7	2.5	7.9	7.1	1.1	23.2	0.6	6.4	0.1	0.8	2.0	4.5	**5.6**

(Continued)

TABLE 1 | Continued

	Overall occurrence frequency			**High-level strategy/investments: percent (%) of mentions**						**Operational-level strategy/investments: percent (%) of mentions**										
	Number of time that a challenge term was mentioned	**Number of times that a solution term was mentioned**	**% times in which any solution term was mentioned**	**Co-management strategies**	**Ecosystem-based fisheries management strategies**	**Integrated coastal zone management strategies**	**Investments in people, technology, or infrastructure**	**Fisheries science and assessment**	**Enforcement decisions and initiatives**	**Boundary rules -licensing and access rights**	**Authority rules -gear and vessel restrictions**	**Authority rules -spatial restrictions**	**Authority rules -temporal restrictions**	**Information rules -monitoring and reporting**	**Information rules -labeling and certification**	**Scope rules -restrictions on landing size, types, or daily bag limits**	**Scope rules -restrictions on landing amounts and quotas**	**Payoff rules -financial incentives**	**Initiatives to change social norms and individual values**
FISHERIES MANAGEMENT																				
Fisheries management-general issues	6,451	4,258	**66.0**	11.2	7.7	5.0	4.1	8.7	5.7	4.2	3.0	29.6	1.4	7.2	0.2	2.3	4.2	3.1	2.5
Aquaculture	1,512	308	20.4	14.0	3.9	**12.0**	**12.3**	6.8	6.5	**8.8**	0.6	13.6	0.3	10.7	**0.6**	0.6	2.3	3.6	3.2
Compliance issues	1,226	854	**69.7**	10.1	3.0	3.4	3.9	3.9	**16.0**	6.4	4.2	27.6	1.8	5.0	0.1	2.6	3.0	**5.3**	**3.6**
Non-fishing marine tourism	2,021	878	43.4	11.6	2.6	**11.6**	6.0	1.4	7.2	3.5	0.9	**37.9**	0.2	5.4	0.1	0.7	1.0	4.9	**4.9**
Ornamental fisheries	215	56	26.0	5.4	1.8	1.8	7.1	3.6	8.9	5.4	3.6	30.4	1.8	3.6	0.0	**7.1**	**12.5**	**7.1**	0.0
Recreational fisheries	1,509	802	53.1	5.1	3.1	4.9	5.9	5.9	6.0	6.4	8.0	31.5	1.6	8.4	0.0	**5.0**	2.2	3.0	3.1
EFFECTIVE AND EFFICIENT CAPTURE FISHERIES																				
Fishing mortality	1,988	1,127	56.7	3.2	7.0	1.7	3.2	**20.6**	2.7	2.6	5.7	22.7	2.3	14.2	0.0	3.6	**7.4**	2.3	0.9
Fishing strategies	688	486	**70.6**	5.1	6.8	0.8	3.7	10.7	3.9	4.5	6.4	23.0	**3.3**	15.6	**0.6**	1.2	7.2	4.1	2.9
Target species	2,942	1,351	45.9	4.7	8.1	1.8	4.5	11.5	4.2	2.1	6.2	32.6	**2.4**	11.0	0.1	3.3	3.4	2.4	1.6
FISHERY SECTORS																				
Artisanal and subsistence sector	1,287	771	59.9	14.5	4.5	2.6	5.4	6.0	6.0	**7.5**	5.7	25.8	1.8	8.8	0.0	2.3	3.6	3.4	1.9
Industrial sector-general	1,841	864	46.9	8.4	6.0	2.2	4.5	10.9	3.5	6.4	5.7	22.8	0.9	11.5	0.2	2.3	**7.4**	5.0	2.3
SPECIFIC FISHERY TYPES																				
Gillnet	484	273	56.4	2.6	3.7	1.1	6.2	11.4	4.0	0.4	**21.6**	21.2	**3.7**	15.4	0.0	2.9	2.9	1.8	1.1
Handline and trolling	313	145	46.3	0.0	2.1	0.0	9.0	9.7	0.0	0.0	**37.9**	10.3	1.4	**18.6**	0.0	**6.9**	2.8	0.0	1.4
Longline	689	379	55.0	1.8	4.7	0.5	7.7	**15.8**	2.9	1.1	**20.3**	15.3	1.8	18.2	0.0	2.4	4.2	2.6	0.5
Other types of fisheries	444	242	54.5	7.0	6.6	1.2	6.2	12.0	3.3	3.3	7.4	24.8	2.1	12.0	**0.8**	**4.1**	5.4	2.5	1.2
Seine	469	175	37.3	2.9	7.4	0.6	6.3	**12.6**	1.7	5.7	9.1	21.1	1.1	17.7	**0.6**	1.1	6.9	4.0	1.1
Trap	71	32	45.1	6.3	3.1	3.1	3.1	0.0	6.3	**9.4**	**12.5**	21.9	**3.1**	15.6	0.0	3.1	6.3	**6.3**	0.0
Trawl	1,729	699	40.4	2.7	**9.0**	0.6	3.7	**13.3**	2.6	2.0	10.0	28.8	**3.0**	15.5	0.1	1.6	4.0	2.3	0.9
Total occurrences	1,59,712	34,684																	
Percent cases when solution mentioned				10.3	6.5	5.3	5.8	7.3	5.6	4.0	3.8	29.2	1.1	10.3	0.1	1.7	3.3	3.0	2.5

**Strategy and instrument proportions sum to 1.00 across rows. Bold indicates the five (six in case of tie for 5th spot) challenges for which each solution category received the highest proportion of mentions (i.e., their relative highest contributions to challenges calculated vertically for each column).*

3,034 times in article abstracts but phrases associated with possible solutions were mentioned only 350 (11.5% of the total) times; of those 350 mentions of possible solutions, *co-management* was mentioned in conjunction with sea level rise most often (29.1%) and *ICZM* was mentioned second most frequently (27.1%, the highest proportion for ICZM among any challenge).

The bolded text in **Table 1** highlights those cells that had the highest relative proportion of co-occurring cases in each column, for each policy instrument or strategy. Bold indicates the five (six in case of tie for 5th spot) challenges for which each solution category received the highest proportion of mentions (i.e., their relative highest contributions to challenges calculated vertically for each column). For example, *authority rules—spatial restrictions* was relatively most often mentioned in conjunction with these five challenges: *ocean warming* (the solution spatial restrictions was mentioned in 51.4% of cases where any solution was mentioned in conjunction with ocean warming); *invasive species*; *spatial issues—general*; *environmental conservation planning*; and *non-fishing marine tourism*.

While there is a large amount of potentially valuable information in this table, I highlight only select results. First, for challenges arising due to commercial or recreational fishing, at least one possible solution was also mentioned 40–70% of the time. For operation-level instruments there was substantial variation in the patterns of co-occurrence, suggesting that patterns of instrument preferences do exist for specific types of fisheries and that those patterns can be identified. Aquaculture, which often falls under the mandate of fisheries management, showed a distinct pattern of instrument co-occurrence compared to commercial fisheries.

On the other hand, for global environmental change challenges, the proportion of times that articles simultaneously mentioned at least one possible solution was much lower, in the range of 6% (ocean acidification) to 12% (sea level rise). Proportions were even lower for the challenges of algal blooms and toxins (6%), contaminants (4%), and heavy metals (3%). Co-management strategies were most commonly mentioned as a co-occurring solution with global environmental change challenges. The three alternative management strategies—co-management, EBFM, and ICZM—were relatively distinct in the types of challenges with which they tended to co-occur (e.g., while co-management and ICZM had similar patterns with regards to environmental change, ICZM was hardly mentioned in conjunction with fishing-related challenges; EBFM co-occurred most frequently with trophic structure challenges).

Enforcement co-occurred with human health (e.g., zoonotics, pathogens) in 39% of cases. Monitoring co-occurred relatively frequently with algal blooms and toxins, contaminants, and heavy metals. Social norm-seeding solutions co-occurred relatively frequently with the marine plastics challenges. Finally, spatial authority rules co-occurred with each of the 40 challenges at least at the 10% level; for ocean warming, the proportion was over 51%. Unlike gear-oriented authority rules (which were only really relevant for bycatch and particular fishing fleets), spatial-oriented rules were mentioned in conjunction with all ocean sustainability challenges.

Temporal Shifts in Issue Importance

For each ocean challenge and potential solution, **Table 2** shows the results of comparisons of category frequency for the time periods 2006–13 and 2014–15. The values shown in **Table 2** include *z*-scores, a measure of the strength by which terms comprising a category occurred significantly more (significant positive scores, 2-tailed *p*) or less (significant negative scores) than expected. Even though overall publication rates increased from 14,903 to 25,701 articles between 2006 and 2015, numerous issues appeared to emerge as "hot topics" over the last 2 years (e.g., 10 topics had scores of $z > 9.2$). Those included (in order from highest possible deviation from expected value—recent over-representation among the topics): marine plastics and debris; environmental conservation; social impacts; ocean acidification; terrestrial influences—general; co-management strategies; climate change—ocean warming; boundary rules—licensing and access rights; oil spills; and economic impacts. The MDS analysis supported the view that importance over time (Supporting Information S2).

Temporal Citation Patterns

Table 3 shows the number of abstracts for all challenge and solution categories that were, for each year during the 10-year period, among the top quintile (20%) of articles cited for that year. For clarity, categories with 10 or less citations in the top quintile for all 10 years were dropped from the table. To illustrate, the first row shows that for a 2006 paper to be in the top quintile, it would have had 40 citations at the time the database was downloaded (July 2016); for more recent articles from 2014 to 2015, only 5 and 2 citations, respectively, would have been needed to be in the top quintile. 2010 was anomalous in that an article published in that year needed only 16 citations to be in the top quintile; a more recent 2011 paper would have needed 20 citations to make the standard.

The table highlights how global environmental change articles are consistently among the most cited: general climate change, ocean warming, and ocean acidification consistently featured in the top quintile from 2007. Challenges relating to ecosystem trophic structure were also highly cited for 9 of the 10 years, and marine plastics and debris for the most recent 8 years. Ecosystem-based management articles, on the other hand, were among the more highly cited over the first 6 years but have since disappeared from the top quintile.

Highly cited oil spill articles appeared on the list in 2011 and 2012. Sometimes important focusing events can lead to a rapid (typically around 2 years later) increase in publications in a field (Small et al., 2014).

DISCUSSION

Text analytics and text mining advances may open possibilities to assess scientists' professional writing and identify emergent challenges or policy/management solutions receiving increasing academic attention. From 50,817 potentially relevant abstracts drawn from journal articles published from 2006 to 2015 in ocean and coastal science and management, different patterns

TABLE 2 | Expected (based on 2006–13 phrase frequency) versus observed challenge and solution phrase frequency of occurrence om 2014–15, overall 2014–15 case occurrence, and phrase deviation from expected occurrence.

	Cases 2014–15	Expected mentions 2014–15	Observed mentions 2014–15	Deviation (%)	*z*-score
ENVIRONMENTAL CHALLENGES					
Algal blooms and toxins	1,759	4,400	4,175	−5.1	−3.38***
Climate change–general	4,839	7,670	9,003	17.4	15.22***
Climate change–ocean acidification	572	541	919	70.0	16.25***
Climate change–ocean warming	440	592	750	26.7	6.48***
Climate change–sea-level rise	873	1,269	1,449	14.2	5.05***
Contaminants	3,654	10,260	9,986	−2.7	−2.70***
ENVIRONMENTAL EFFECTS OF FISHING					
Bycatch, discarding, entanglement	434	989	1,146	15.9	4.99***
Habitat degradation	2,410	3,532	3,687	4.4	2.60***
Ecosystem trophic structure	1,815	2,664	2,791	4.8	2.45**
Heavy metals	3,046	12,241	11,823	−3.4	−3.78***
Human health and disease (zoonotics)	876	1,641	1,699	3.5	1.42
Invasive species	844	2,129	2,344	10.1	4.64***
Marine and plastic debris	422	696	1,416	103.6	27.30***
Oil spills	414	612	918	49.9	12.33***
Overfishing	514	609	691	13.6	3.32***
Seafood trade and market demand	594	673	806	19.9	5.13***
Spatial issues-general	5,616	8,166	8,430	3.2	2.92***
Terrestrial influences-general	2,220	2,092	2,814	34.5	15.77***
SOCIAL CONCERNS-GENERAL					
Environmental conservation planning	2,819	5,625	4,479	36.9	21.12***
Economic impacts	1,088	1,285	1,618	25.9	9.28***
Justice and fairness	390	523	586	12.1	2.74***
Social impacts	1,752	1,882	2,696	43.2	18.75***
FISHERIES MANAGEMENT					
Fisheries management-general issues	1,956	2,304	2,707	17.5	8.39***
Aquaculture	376	698	669	−4.1	−1.07
Compliance issues	389	508	711	40.0	8.99***
Non-fishing marine tourism	510	1,161	1,138	−2.0	−0.66
Ornamental fisheries	50	100	82	−17.9	−1.73*
Recreational fisheries	404	769	736	−4.3	−1.17
EFFECTIVE AND EFFICIENT CAPTURE FISHERIES					
Fishing mortality	515	811	817	0.7	0.19
Fishing strategies	226	209	301	44.1	6.34***
Target species	799	923	965	4.6	1.37
FISHERY SECTORS					
Artisanal and subsistence sector-general	389	502	618	23.0	5.14***
Industrial sector-general	516	570	600	5.2	1.23
SPECIFIC FISHERY TYPES					
Gillnet	122	239	186	−22.2	−3.40***
Handline and trolling	69	177	128	−27.6	−3.64***
Longline	159	363	335	−7.8	−1.46
Other types of fisheries	115	198	201	1.6	0.19
Seine	126	296	331	11.7	1.99**
Trap	22	33	25	−23.5	−1.26
Trawl	407	911	767	−15.8	−4.76***

(Continued)

TABLE 2 | Continued

	Cases 2014–15	Expected mentions 2014–15	Observed mentions 2014–15	Deviation (%)	*z*-score
SOLUTIONS-IMPLEMENTATION LEVEL					
Co-management strategies	578	607	996	64.1	15.76***
Ecosystem-based fisheries management	300	291	365	25.3	4.29***
Integrated coastal zone management strategies	277	549	449	−18.1	−4.23***
Investments in human/physical capital	336	460	470	2.2	0.46
Fisheries science and assessment	330	401	490	22.3	4.44***
Enforcement decisions and initiatives	274	300	374	24.6	4.23***
SOLUTIONS-OPERATIONAL LEVEL					
Boundary rules-licensing and access rights	285	243	453	86.4	13.44***
Authority rules-gear and vessel restrictions	135	298	239	−19.8	−3.39***
Authority rules-spatial restrictions	1,386	2,551	2,730	7.0	3.53***
Authority rules-temporal restrictions	42	44	63	43.0	2.78***
Information rules-monitoring and reporting	474	581	645	11.1	2.64***
Information rules-labeling and certification	11	11	25	134.6	4.24***
Scope rules-restrictions on landing types	62	89	79	−11.0	−0.99
Scope rules-restrictions on landing amounts	125	275	269	−2.2	0.33
Payoff rules-financial incentives	100	151	149	−1.5	0.15
Initiatives to change social norms and values	137	134	181	34.8	3.99***

, **, and * refer to 10, 5, and 1% significance levels respectively.*

of co-occurring text associated with challenges and potential solutions were discernable.

Substantive Issues in Ocean Research

While the focus of this paper is largely on methodology for identifying instruments, there were several findings of direct interest for ocean science and policy. First, with regards to alternative management strategies or paradigms (co-management, ICZM, EFBM), there were clear differences in their focus. ICZM was mentioned at a relatively high rate in conjunction with sea level rise, but with few other issues. Co-management strategies co-occurred at much higher rates with global environmental changes issues relative to EBFM, where the focus was more on trophic level effects of fishing. Co-management was also mentioned frequently in conjunction with social impact and justice/fairness concerns.

The temporal analysis (including the MDS, Supporting Information S2) provided some general support for the idea that ecologically-oriented ocean research was in the midst of a "social turn" (e.g., Klein et al., 2015). Within the research field, there has been recent recognition that ecological factors may have been excluded in much of the recent socio-ecological system literature and that more balance may be needed between ecological and social conditions (e.g., Vogt et al., 2015).

The widespread association of spatial regulations with all ocean challenges was also of interest. Terms associated with spatial restrictions of one sort or another (i.e., fishing restrictions, no-take protected areas, ocean zoning, marine parks) co-occurred relatively frequently with challenges associated with global environmental change (as high as 51.4% for ocean warming). While abstracts focusing on fishing challenges also had relatively high levels of co-occurrence between challenge and solution categories (often in the 30% range), there were some fishing sectors where spatial restrictions were relatively unimportant (e.g., longline and handline/trolling). Clearly there is a diversity of views on what spatial restrictions can and should be used. The relatively heavy emphasis on challenges arising from global environmental change may help explain some of the ongoing controversy in the scientific literature, where criticism of MPAs is sometimes based on the view that MPAs are not comparatively effective and efficient tools for fisheries management relative to other types of instruments. Some scientists are skeptical of the role MPAs can play in broader non-fisheries challenges. For example, Hilborn (2015) argued that MPAs "provide absolutely no protection from any of" the major ocean threats, "global warming, ocean acidification, pollution, illegal fishing, land-based runoff of sediments, and plastics" (p. 1326). Clearly that is not a shared view among scientists publishing on marine spatial planning and regulation over the past decade: a cursory examination of keywords in context for the MPA papers showed that many scientists perceived the benefits of MPAs to be related to the ecological resilience they bestow in the face of ever-increasing and multiple stressors due to both climate change and upland pressures (e.g., Halpern et al., 2008). The spatial management of oceans is clearly an area where multiple epistemic communities, discourse coalitions, and advocacy coalitions (Weible and Sabatier, 2005; Caveen et al., 2013) are operating near the science-policy interface,

TABLE 3 | Number of highly-cited articles (top 20% of citations of articles for the year) by challenge and solution category; based on total ISI citations at the time of Web of Science data download (July 2016).

Citations needed to be in top 20%	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	40	37	32	29	16	20	15	10	5	2
ENVIRONMENTAL CHALLENGES										
Algal blooms and toxins			166	169	288	168			244	
Climate change–general	337	401	449	451	821	553	680	749	833	694
Climate change–ocean acidification		15	37	60	93	106	118	174	134	101
Climate change–ocean warming		34	42	45	66	64	76	76	78	72
Climate change–sea-level rise			61	66		96	106			
Contaminants									535	407
Environmental effects of fishing										
Bycatch, discarding, entanglement		27								
Habitat degradation								267	379	
Ecosystem trophic structure	127	151	169	172	281	176	197		268	239
Heavy metals		230								
Human health and disease (zoonotics)		68								
Invasive species	60	80		59	147	81				
Marine and plastic debris			12	21	55	38	42	67	92	64
Oil spills						31	42			
Overfishing						48				
Spatial issues-general	328				795					
Terrestrial influences-general		101								
FISHERIES MANAGEMENT										
Fisheries management - general issues					483					
Compliance issues					42					
EFFECTIVE AND EFFICIENT CAPTURE FISHERIES										
Fishing strategies							22			
Target species	47									
SOLUTIONS-IMPLEMENTATION LEVEL										
Co-management strategies			31							
Ecosystem-based fisheries management	12	19		29	46	30				
Fisheries science and assessment										42
SOLUTIONS-OPERATIONAL LEVEL										
Authority rules-spatial restrictions				102	183					
Initiatives to change social norms and values					19					

highlighting the potential for using marine spatial management as a detailed case study for further text mining research.

In addition, the analysis was able to flag the publication effect of a major focusing event, the 2010 BP Deepwater Horizon spill. In this case, the Deepwater Horizon spill in April 2010 quickly appears to have led to a surge in articles in 2011 and 2012, many of which become highly cited by 2016; 25% [65 of 260 articles] over that 2 year period were directly related to the Deepwater Horizon spill.

Identifying Solutions in Article Abstracts

This research demonstrated that different types of instruments, investments, and strategies potentially useful in addressing ocean sustainability challenges can be identified in the abstracts of academic articles. The proportion of abstracts that mentioned possible solutions for particular challenges ranged from 2.7% (heavy metals) to 70.6% (fishing strategies). This may partly be a function of the nature of information provision in the chemistry/ecotoxicology and fisheries fields. Rudd (2015b) found that a high proportion of physical scientists tended to be "evidence providers" whose own perceived role at the science-policy interface ended when information was passed to decision makers: they may thus be unlikely to mention any policy instruments in their abstracts. On the other hand, many scientists in fisheries may be more likely to collaborate with managers ("collaborative science communicators" in Rudd, 2015a) or be advocates of high-quality science that compels policy-makers to take action ("advocates for science-based policy" in Rudd, 2015a). Fisheries scientists often straddle the boundary between information and advocacy (Rice, 2011; Caveen et al., 2013; Dankel et al., 2016), so are also much more likely to be engaged in applied research on specific policy alternatives. Using a dictionary that accounts for sentiment or valence (attractiveness; averseness) could greatly aid in identifying more precise identification of policy instruments with potential for positive outcomes with regards to fisheries issues in particular.

Limitations

This was a first exploration of the potential to use text analytics to identify ocean sustainability challenges and associated policy or institutional solutions that have been identified within the scientific literature. As such, there are numerous ways in which this study could be expanded and refined in the future. First, the search used only Web of Science to identify candidate articles, excluding a number of potentially important ocean research journals (e.g., *Frontiers in Marine Science*, which at the time of the download was not yet included in Web of Science). Web of Science provides full records, including citations and literature referenced, for each article and thus, despite not giving a full accounting of all research in the ocean and coastal science realm, provides a large scale picture of activity within both the natural and social sciences. Second, abstracts are so densely written that they pack multiple concepts into single paragraphs; it may be informative to in the future conduct this type of analysis based on sentence-level categorization in addition to the current paragraph-level coding. Third, I did not attempt to look at how solutions were related to sentiment in abstracts (e.g., discerning between text like "MPAs are likely to perform poorly in such contexts" vs. "MPAs provided multiple benefits shortly after their implementation"). Sentiment analysis is possible and has been applied in forestry-oriented text analyses (e.g., Xu and Bengston, 1997) and in the health sciences (e.g., Petrova et al., 2012). As such, it would be possible to develop a specialized dictionary to help assess positive and negative views on instrument attractiveness and effectiveness.

Finally, the dictionary could clearly use more refinement and testing. The degree of refinement would depend on the target audience for ocean sustainability searches. For information professionals and specialist researchers, it may be appropriate to include only terms that have a high degree of precision (proportion of relevant articles retrieved compared to all articles retrieved) and sensitivity (number of relevant articles identified as a proportion of the total number of relevant articles), while for horizon scanning efforts, less stringent criteria may be appropriate to increase the chance that emergent topics are identified. As part of the refinement process, it may also be beneficial to solicit input from scientists with various disciplinary backgrounds to help ensure that phrases from relevant epistemic communities are adequately captured. Having multiple coders would also allow tests of inter-coder reliability. Alternatively, the development of a completely objective approach to dictionary development of a search strategy might be warranted as they can be as accurate as those developed in conjunction with subject experts (Hausner et al., 2015).

CONCLUSIONS

Developing solutions for existing and emerging ocean challenges will require research and action on multiple fronts, including: advancement in forecasting and observing technology and methodologies; improving our understanding of the physical and ecological dimensions of oceans and coastal systems and of the land-sea interface; and developing a much stronger understanding of how science-based policies can be designed and implemented in ways that are effective and efficient. Text analytics does have the potential to help systematically scan new research in ocean and coastal science, identify what instruments are viewed as important by different groups of scientists, and, for different types of ocean challenges, flag trends in instrument prominence and which specific authors, institutions, and journals are publishing research on different types of instruments. Research on the ocean research enterprise itself may, then, help accelerate the identification and implementation of transformative policy-salient topics that support the transition to ocean sustainability.

Scientific abstracts provide tremendous amounts of information on wide-ranging topics relevant to ocean sustainability, from perspectives of both increasing knowledge regarding challenges and informing possible solutions that can improve policies to enhance ocean sustainability. Sifting through the current literature, even within specialized sub-disciplines, has become increasingly challenging as publication rates rise; even considering only ecologically-oriented ocean science research, in excess of 25,000 articles are now published annually.

Taking a text mining approach could help researchers to more objectively identify potential articles for structured or systematic reviews on particular challenges of societal importance (e.g., see (Hausner et al., 2015), who tested highly structured automated text searches in support of systematic reviews in the medical sciences) or the development of new types of horizon scanning exercises (e.g., Small et al., 2014) that expand on current expert-based efforts in environmental science (Sutherland et al., 2011, 2016) or apply horizon scanning initiatives to other societal challenges. A dictionary-based approach also permits for comparisons of textual data from other than Web of Science across sources or times. For instance, horizon scans might greatly benefit from comparisons between articles abstracts and conference abstracts to rapidly identify emergent issues in a timely manner.

In addition to the abstract text used in this analysis, the full bibliometric records from Web of Science also contain other valuable information such as author contact information (i.e., with which to construct highly targeted sample frames) and full article reference information, which could be used for bibliometric coupling (i.e., how closely cited literature matches between different articles) and co-citation analyses (for authors or institutions). While this exploratory research did not examine the composition of author citation networks (e.g., Wallace et al., 2009; Bruggeman et al., 2012), with ongoing technical advances in software for text citation analysis it may be possible in the not-too-distant future to more seamlessly integrate text mining and bibliometric approaches so as to facilitate co-authorship or bibliometric coupling information in more fine-scale analyses of the academic literature. Empirical research on the formation and composition of epistemic communities is relatively sparse in the environmental science (but see (Sandbrook et al., 2011; Reiners et al., 2015; Rudd, 2015b; Spruijt et al., 2016) as examples of empirical research on epistemic communities or in closely related fields). The ability to systematically identify different epistemic communities may help to highlight how different research communities emphasize different types of ocean sustainability solutions, and help ensure that science advice is balanced, reflecting perspectives from a full range of scientific disciplines and communities (Rudd and Lawton, 2013). All in all, the new doors that are opening for large-scale analysis of scientific text could well provide a plethora of new opportunities for researchers studying the environmental science-policy interface.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fmars.2017.00170/full#supplementary-material

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